

## EXCAVATION OF REGOLITH BY IMPINGING JETS OF GAS

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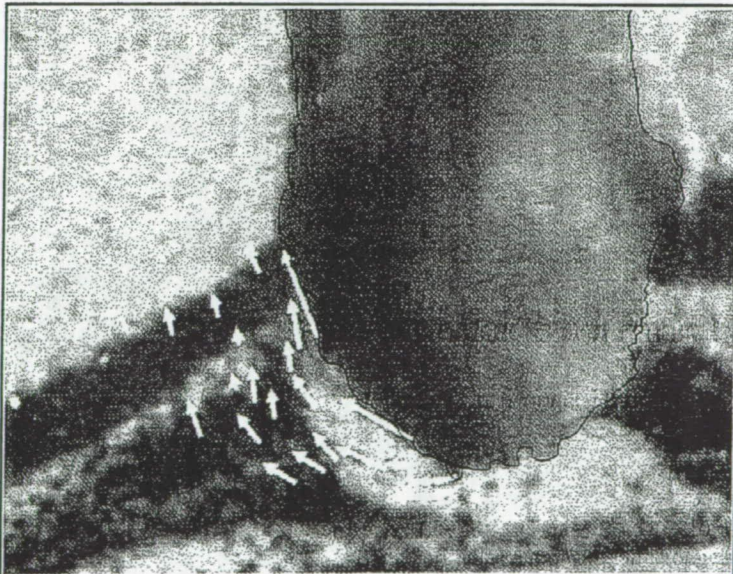
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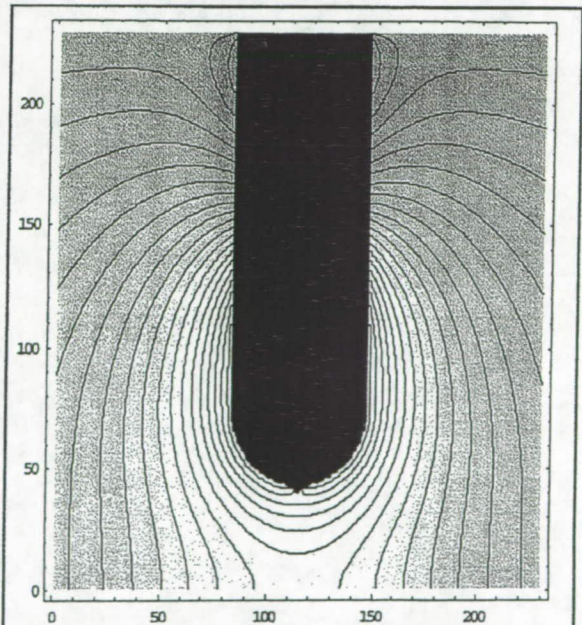
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There are many situations in nature and technology where particulate matter is excavated by a fluid jet. Such a process is often used to excavate soil or to dig wells. Air jets are often used to transport particulate matter such as powders in various industrial processes. Similar situations occur in nature, as when waterfalls scour holes in sand. In other cases, the excavation is unwanted such as when a rocket lands on the sandy or dusty surface of a planet or moon. Recent research into regolith excavation by gas jets has obtained new insights into the physical processes of that excavation, and these may lead to new advances in technology for more efficient fluid-jet excavation processes and for better control of the unwanted excavation effects of landing rockets. This talk will explain the new insights and point to future work supporting lunar exploration.

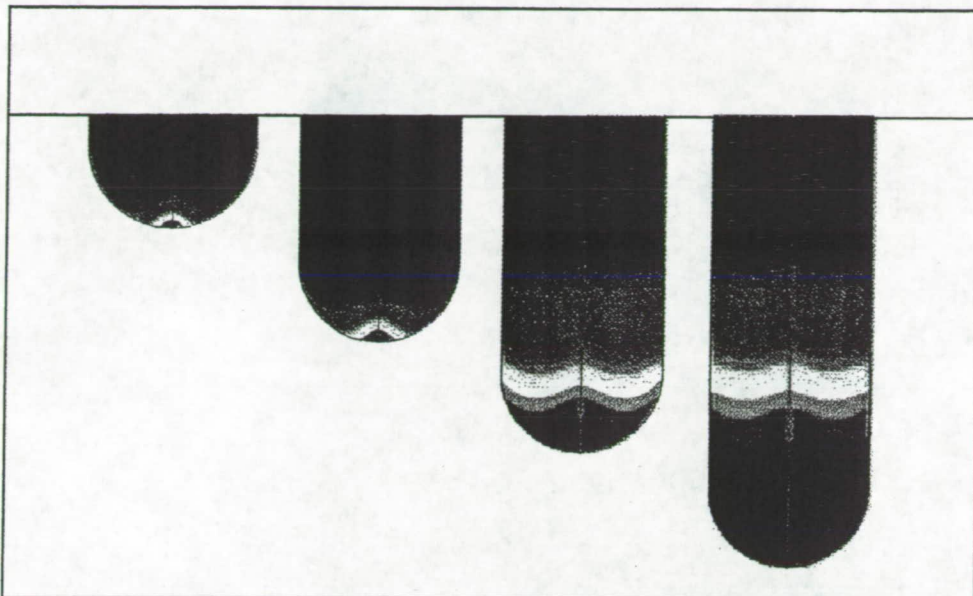


**Figure 1:** Excavated hole (outline red) in white sand with black sand layers. Yellow vectors are the velocities of individual sand particles measured over a small increment of time. Particles travel in the tangential direction around the tip of the hole, contrary to earlier theory.

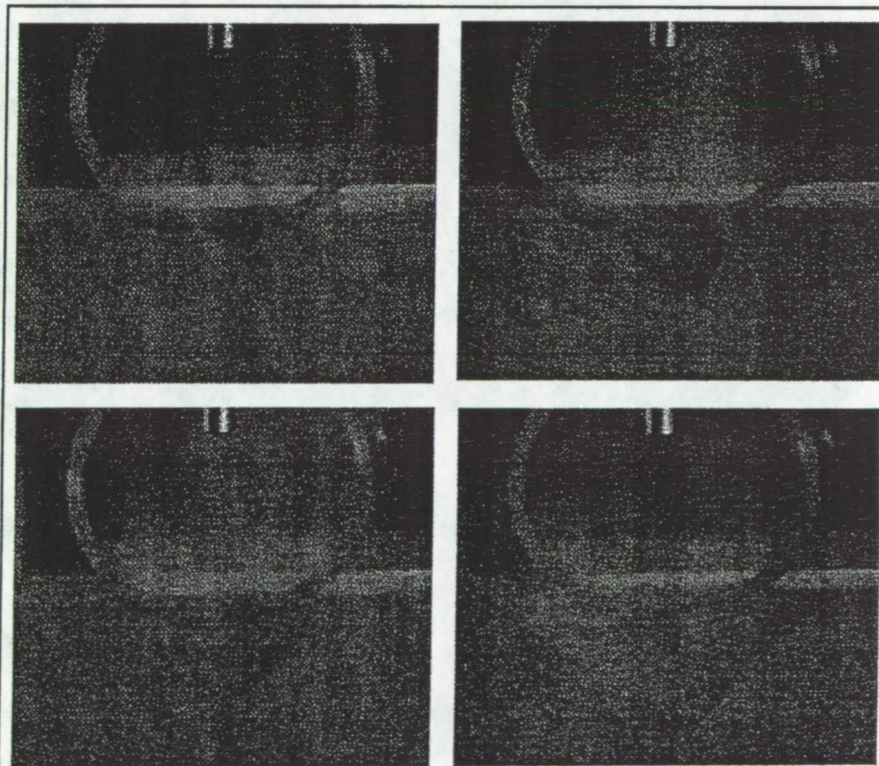


**Figure 2.** Lines of constant pressure within the sand around the excavation hole due to diffusing gases.



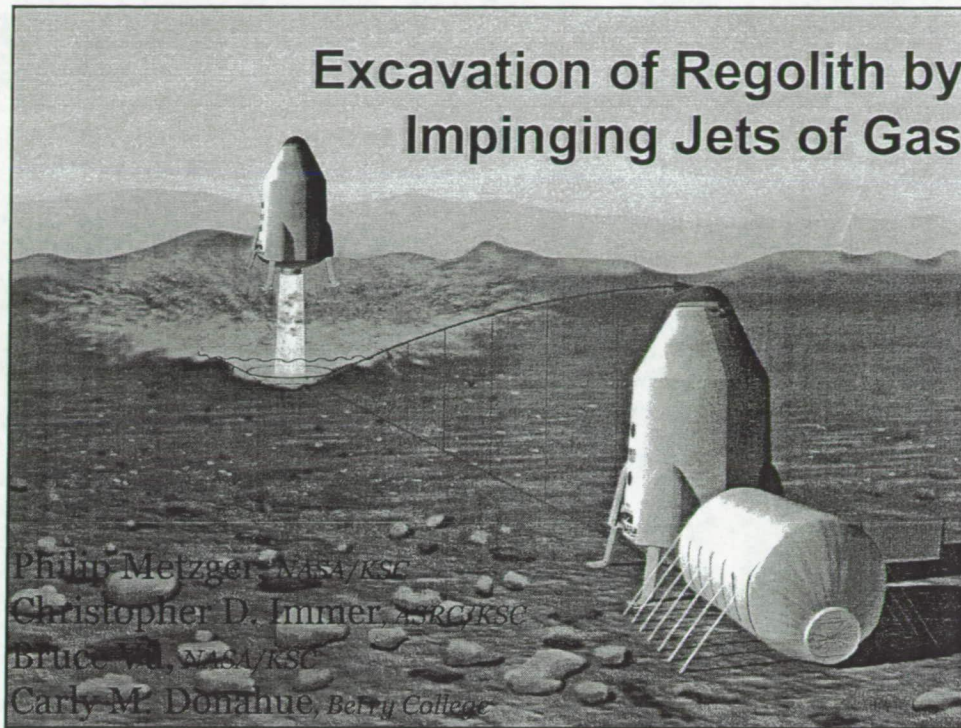


**Figure 3.** A sequence of Computational Fluid Dynamics simulations during jet excavation, showing the gas pressures developed in the hole. Red is higher pressure, and blue is lower. Note that the high pressure gradients are in the tip of the hole when it is small, but along the sides of the hole when it gets deeper. In the deepest hole, there is a large region of stagnant gas at the bottom.



**Figure 4.** Sequence of slow-excavation scour hole growth. (Top left) erosion/fluidization forms a cup. (Top right) Recirculation cell consisting of airborne grains forms inside the cup. (Bottom left) Crater widens until traction along inner surfaces is insufficient to maintain steep sides. (Bottom right) Sides collapse to the angle of repose, producing a recirculating surface layer of rolling grains that return to the inner crater.

## Excavation of Regolith by Impinging Jets of Gas



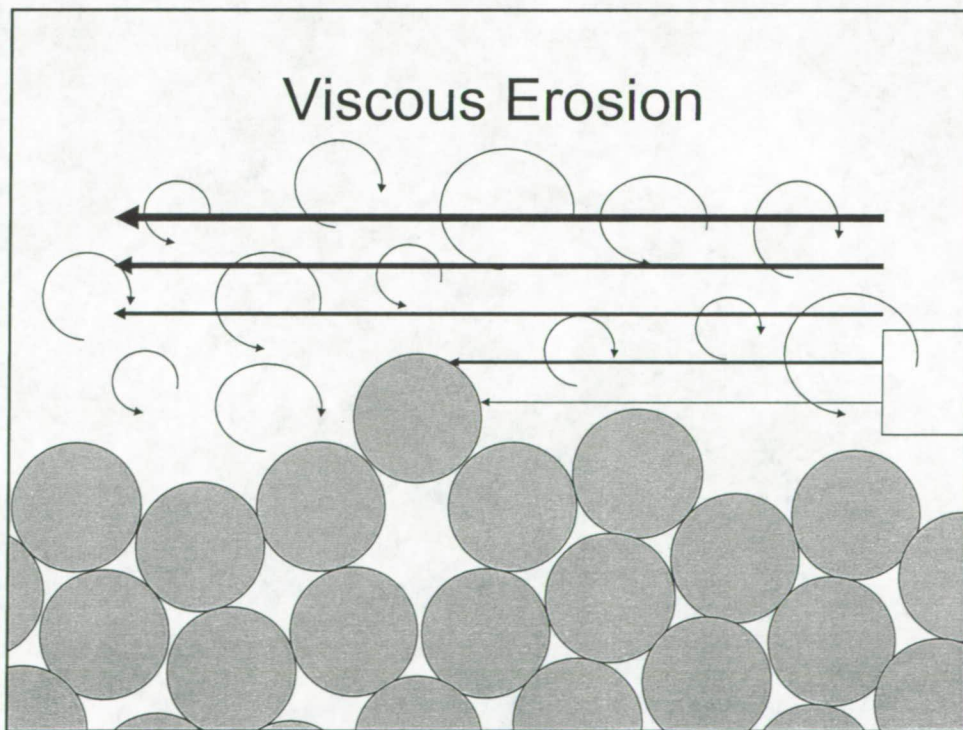
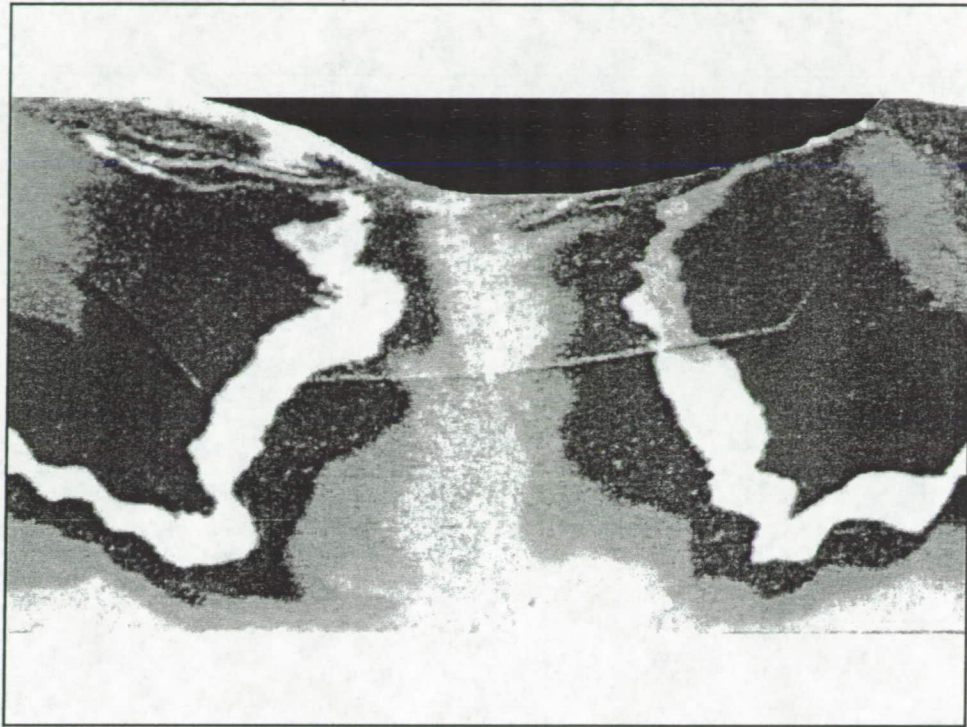
### Froude Number

$$Fr = \frac{\rho_g V^2}{(\rho_s - \rho_g)gd}$$

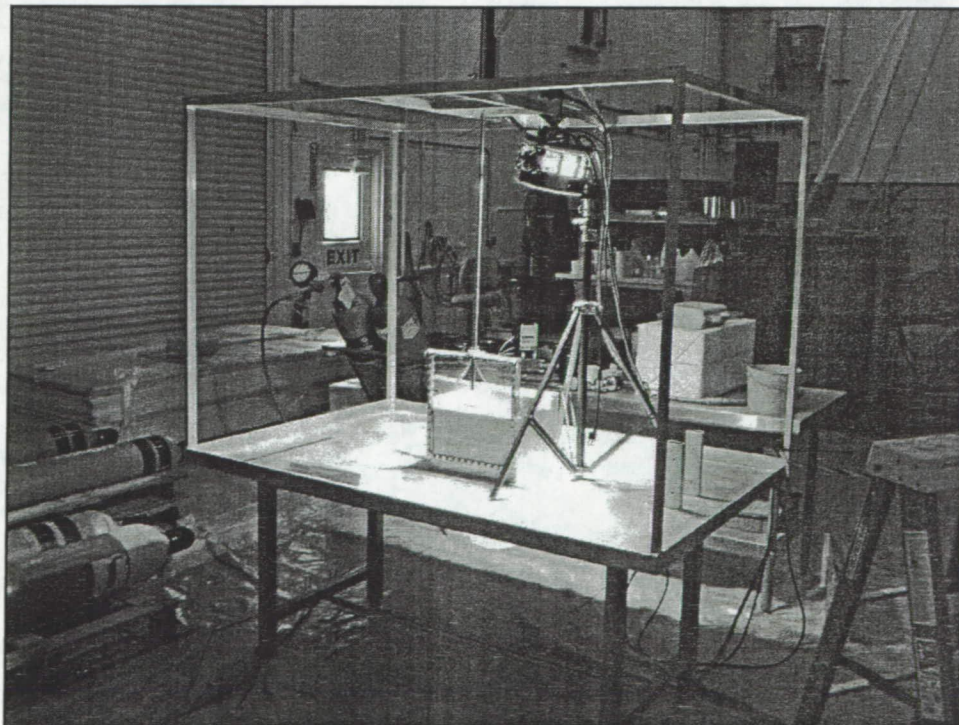
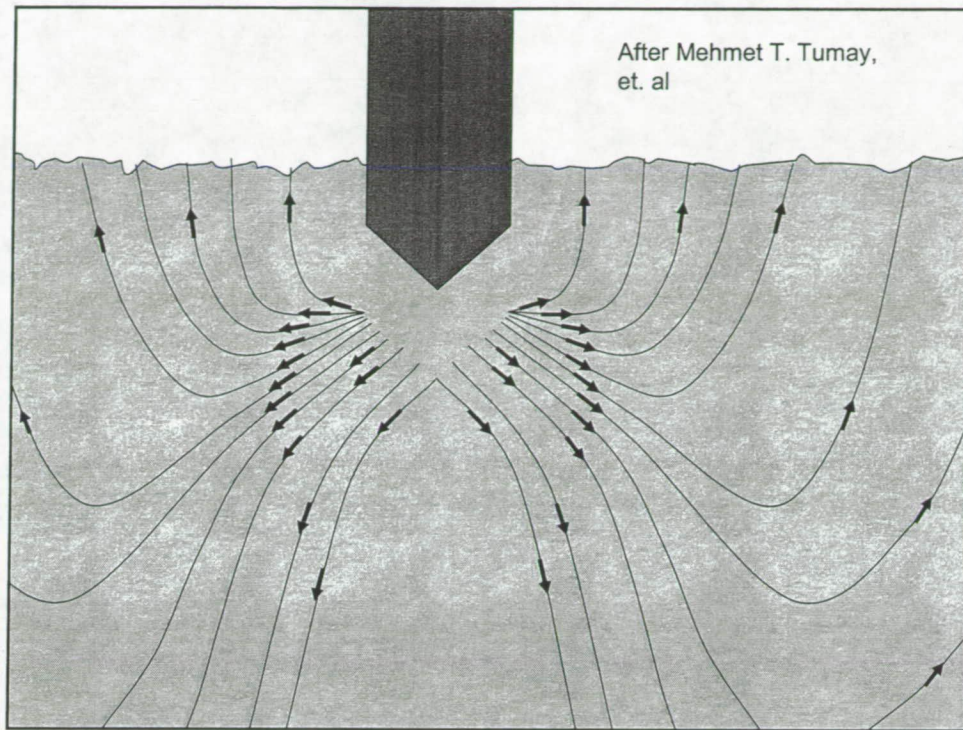
### Erosion Parameter

$$Ec = \frac{Fr D}{H}$$



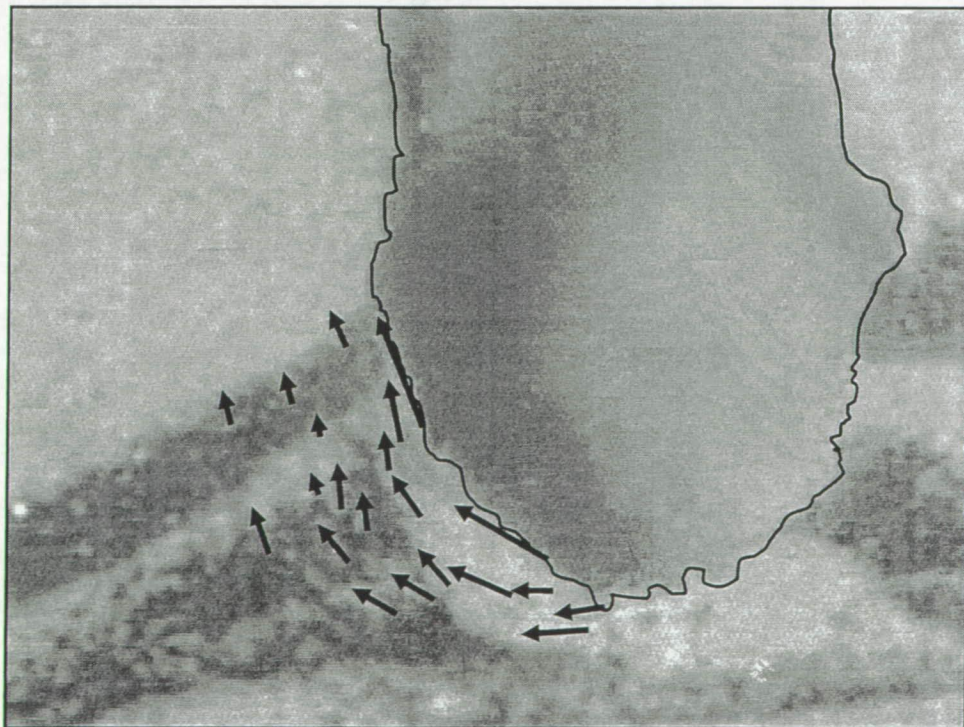
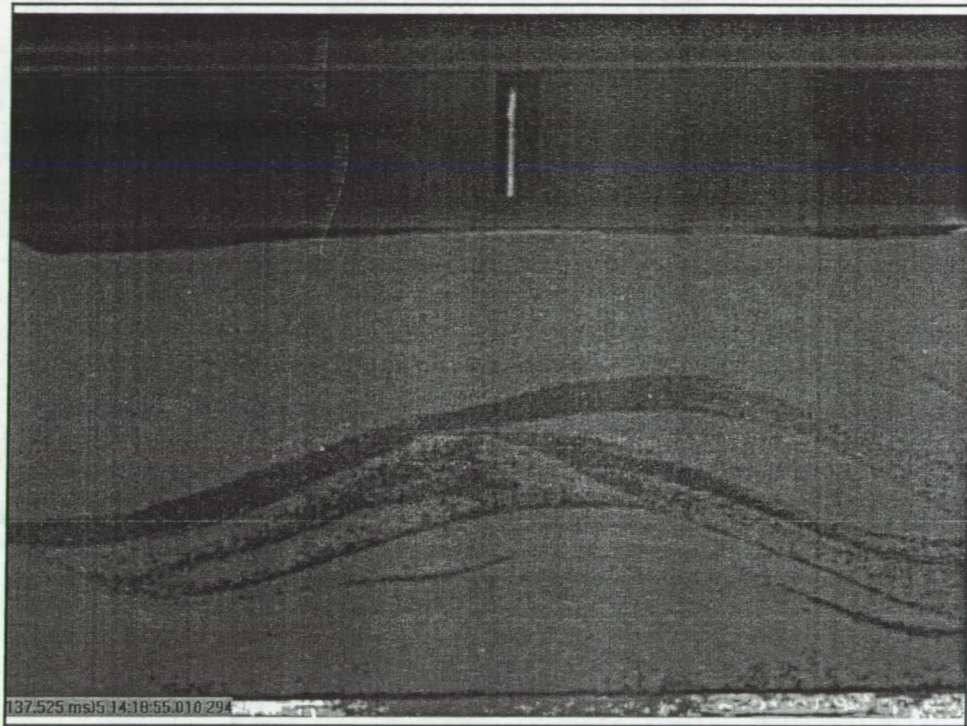


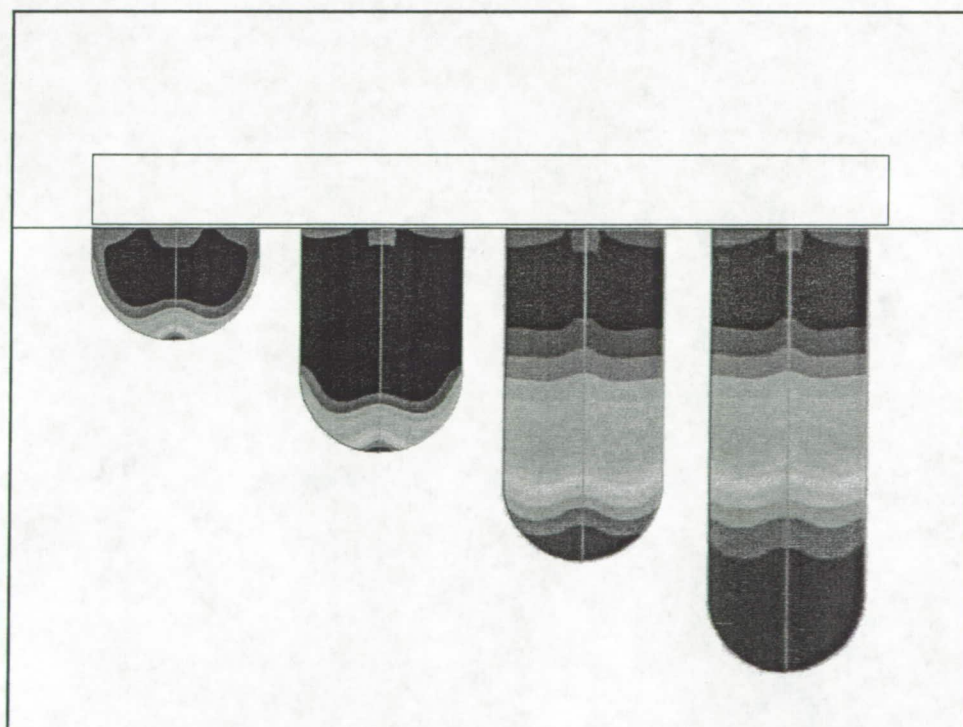
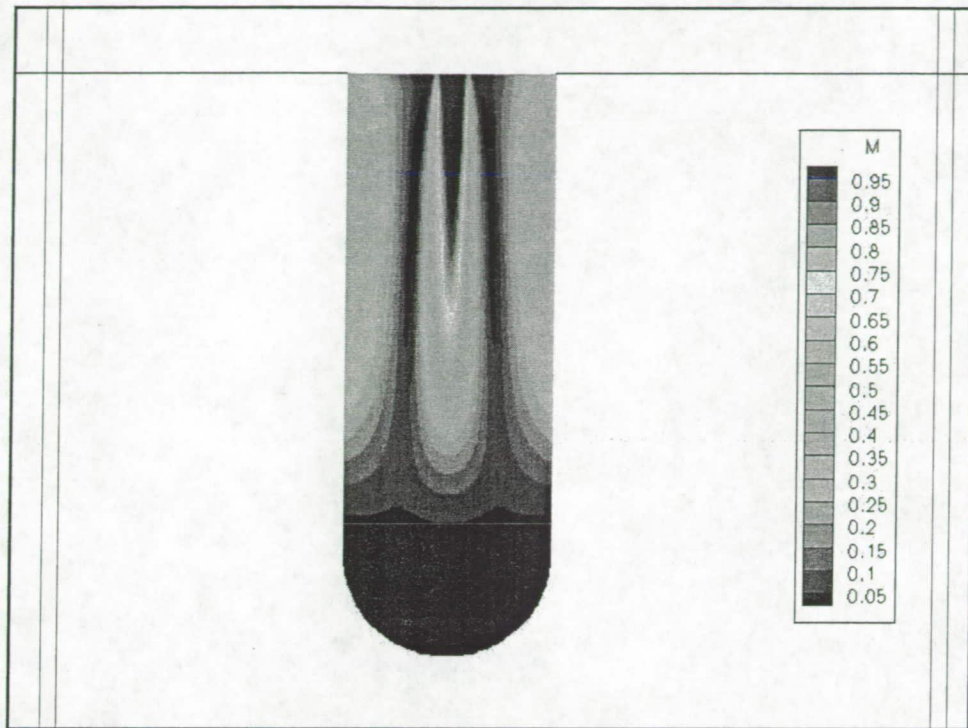




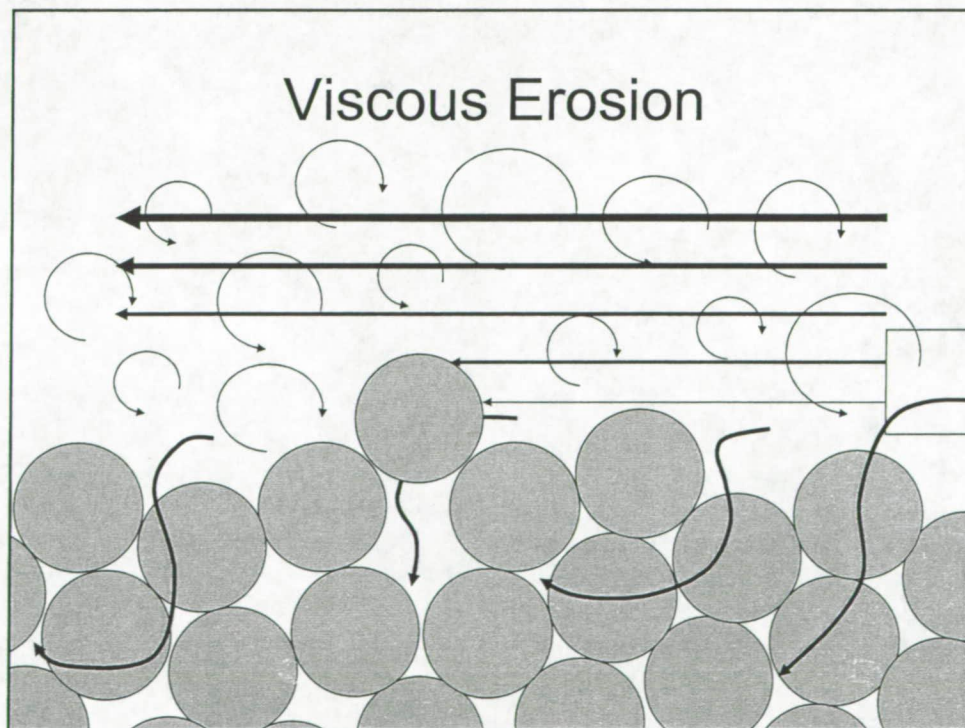
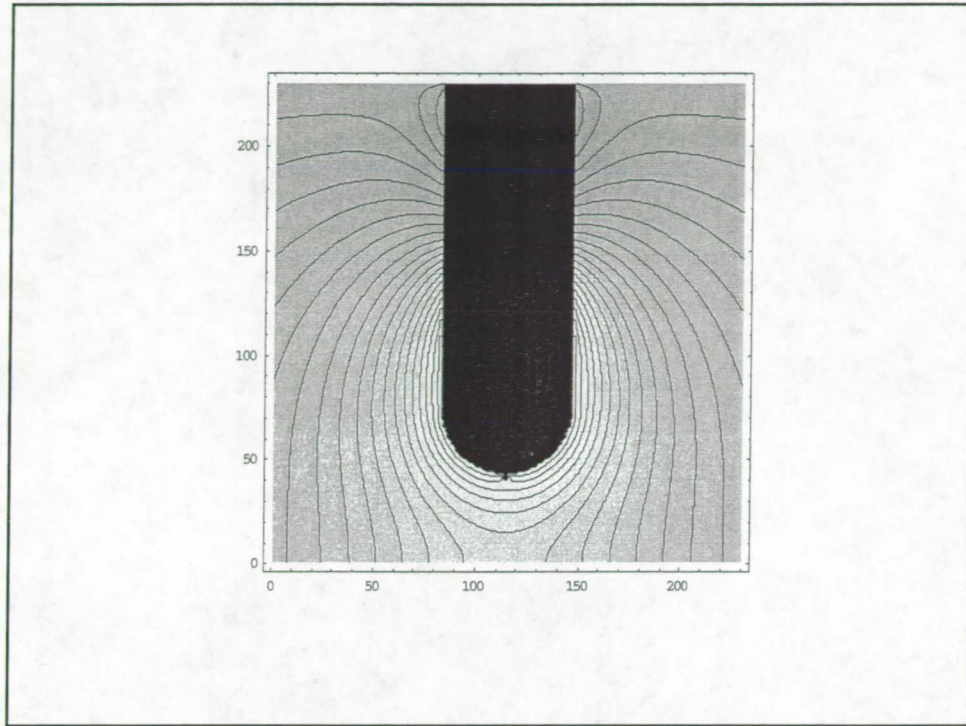
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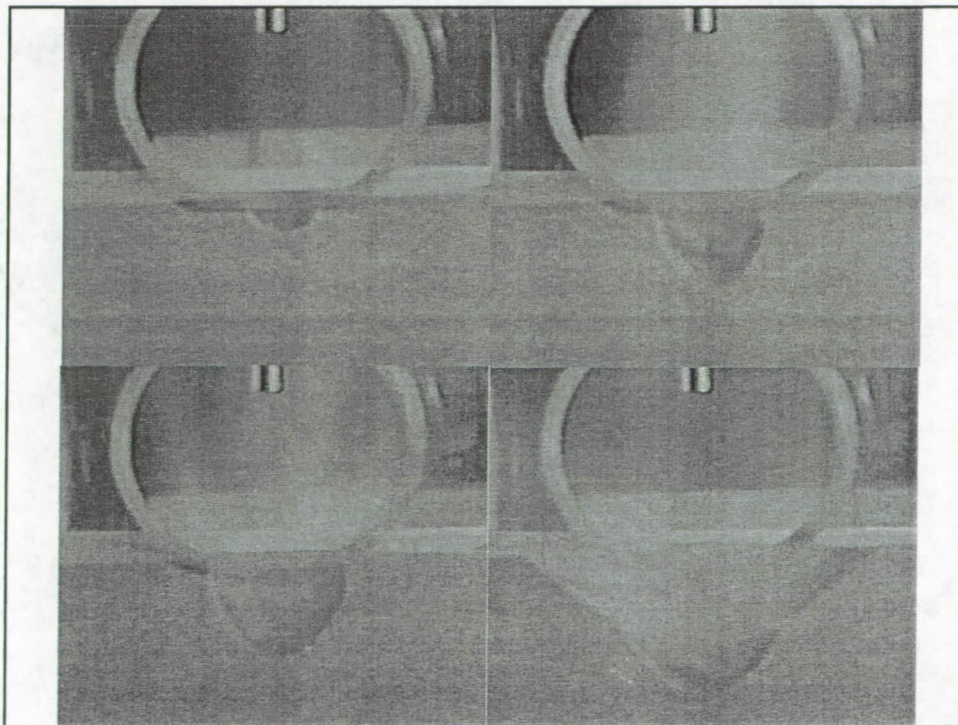
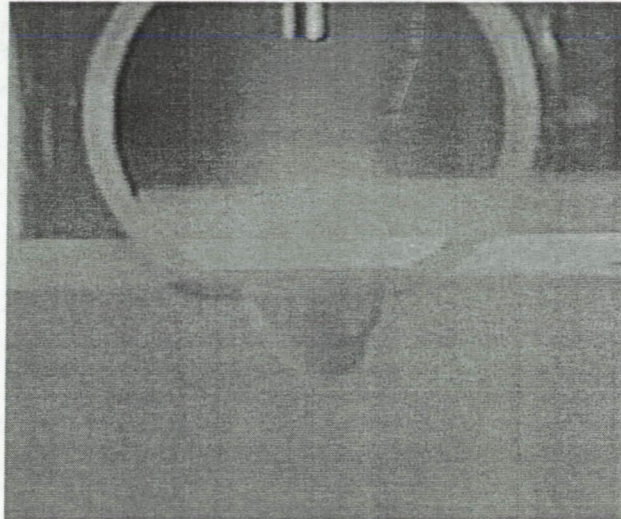




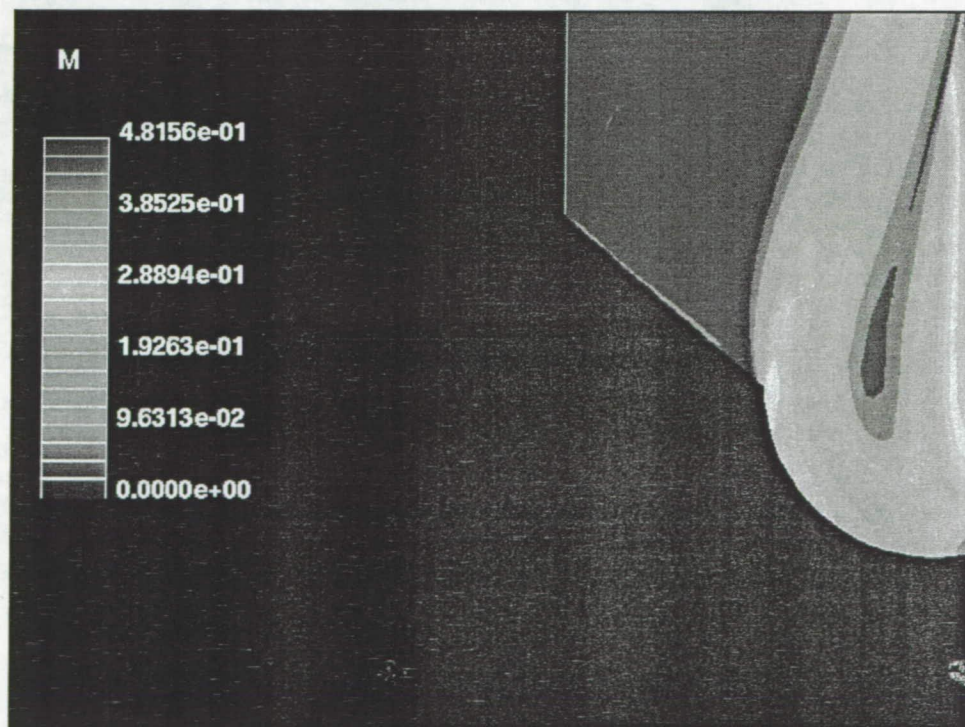
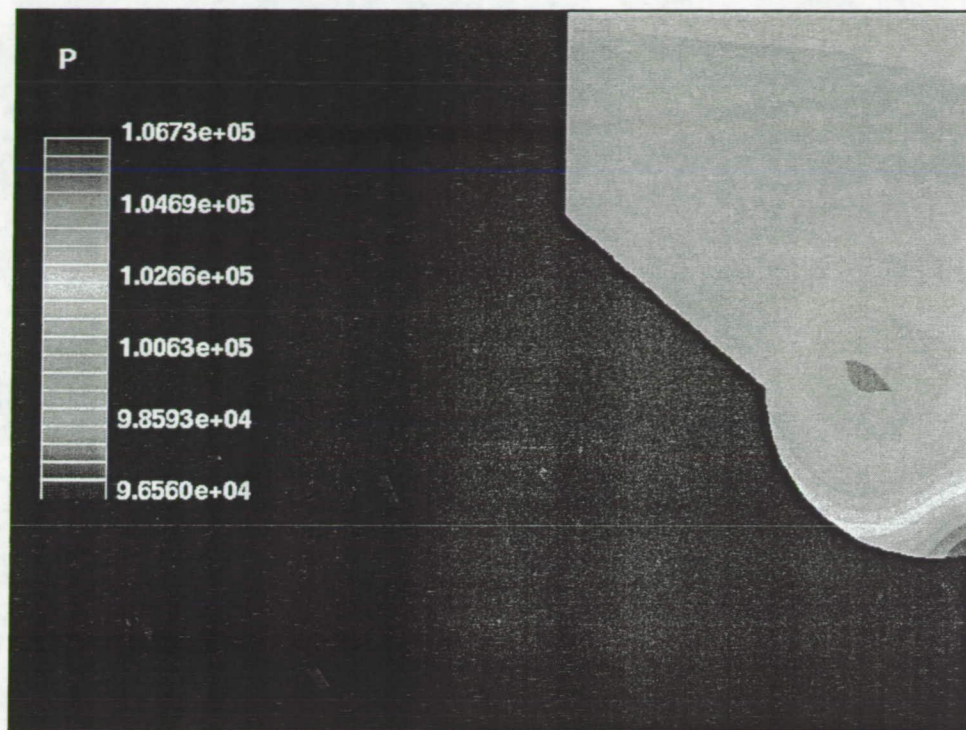


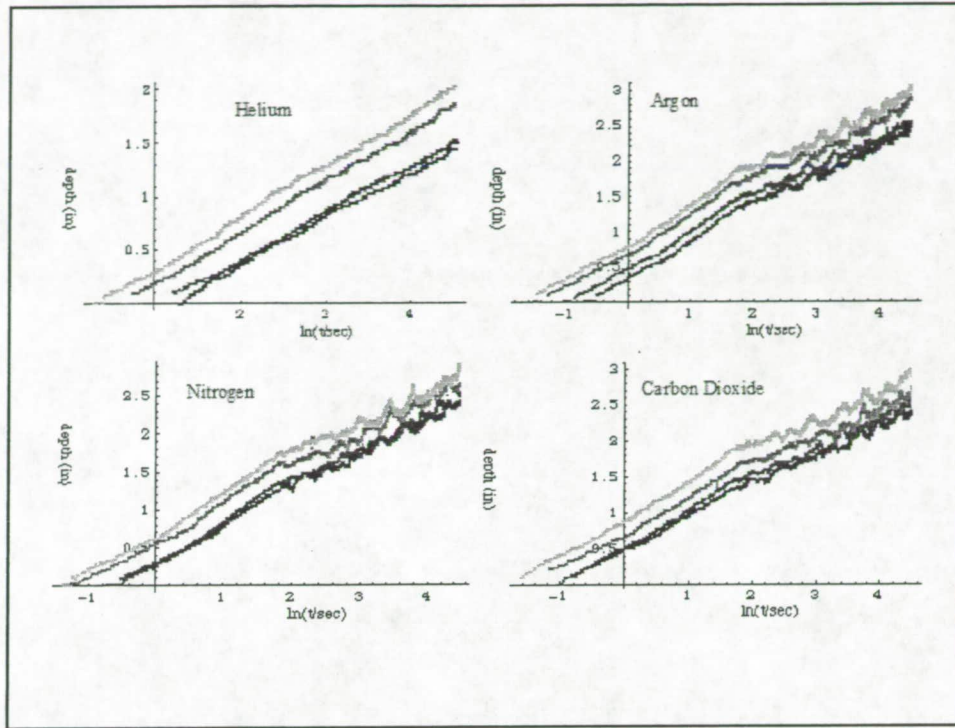


Movie of "slower" deep cratering





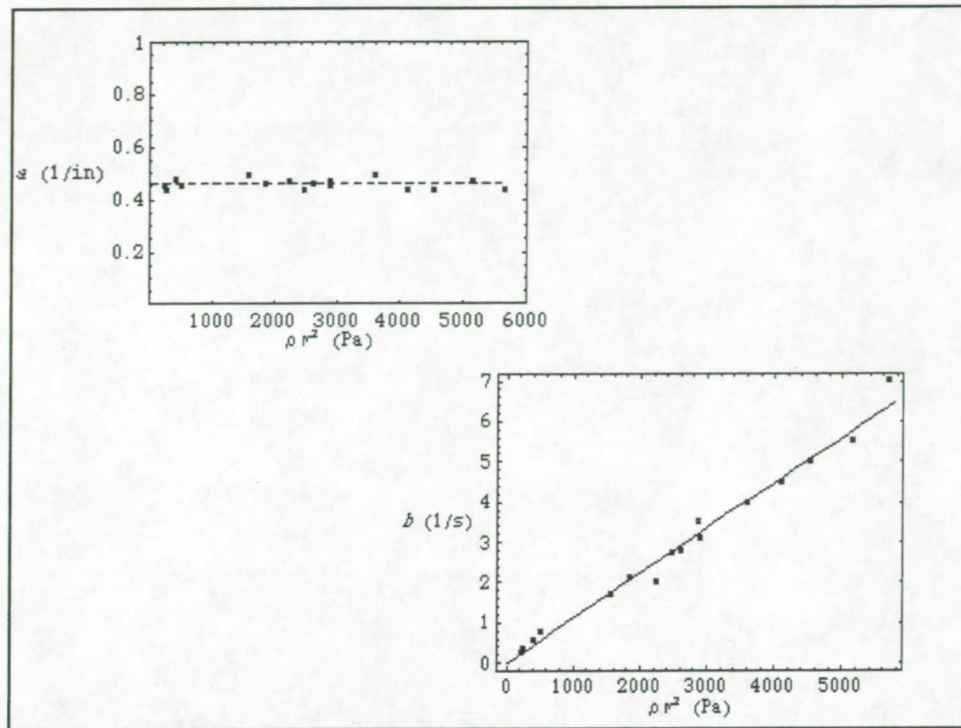




$$d/a = \ln[bt + 1], \quad t > 0$$

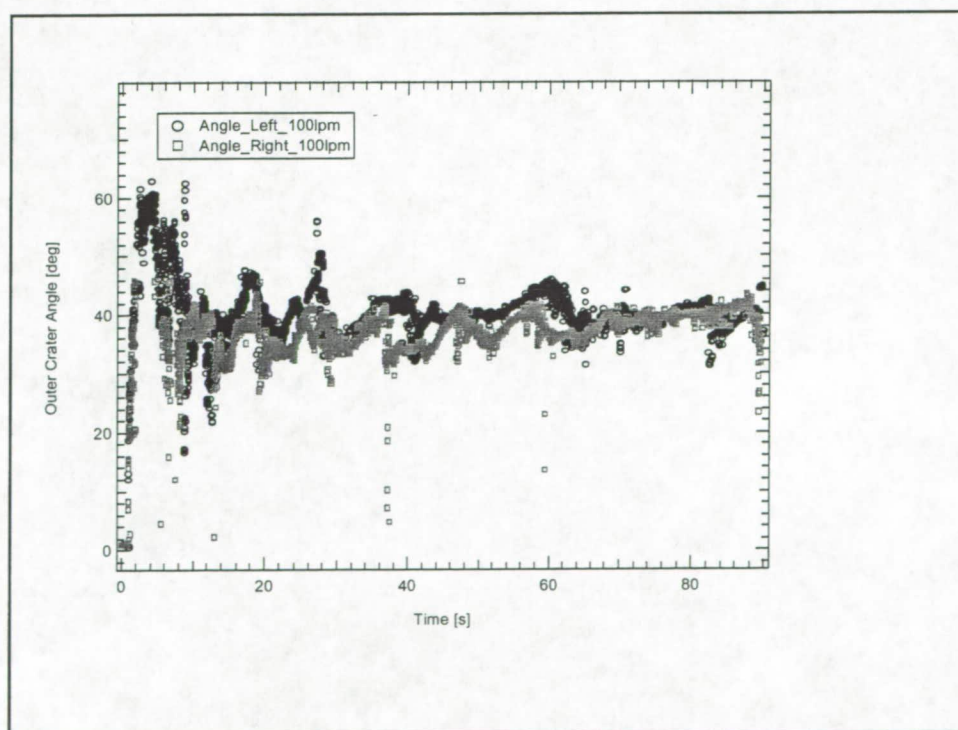
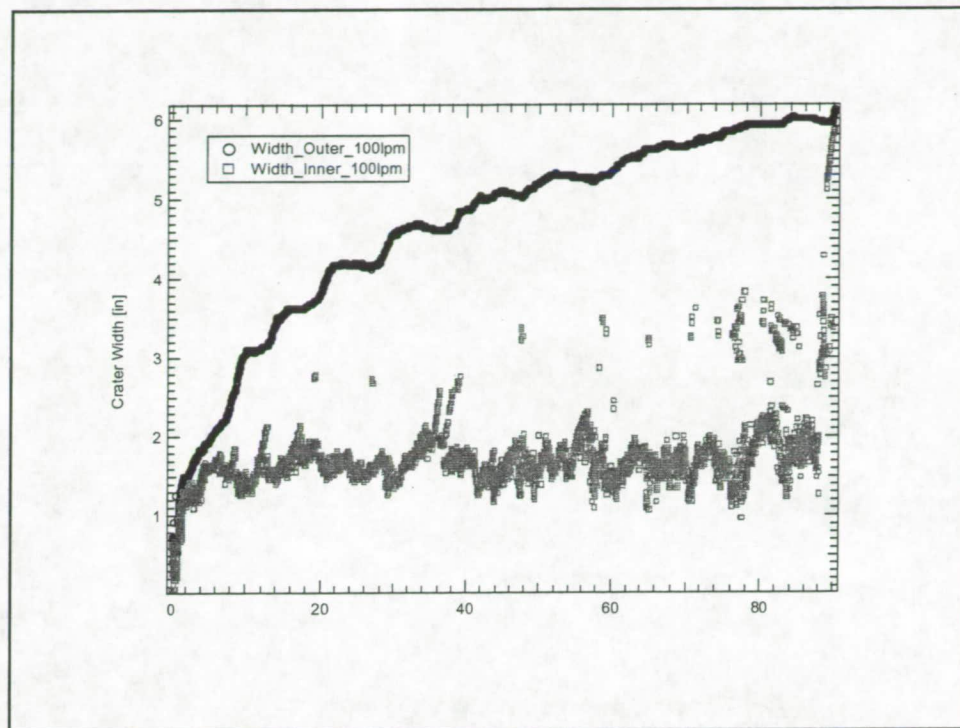
$$(\dot{d}/a) = be^{-(d/a)}, \quad t < t_0$$



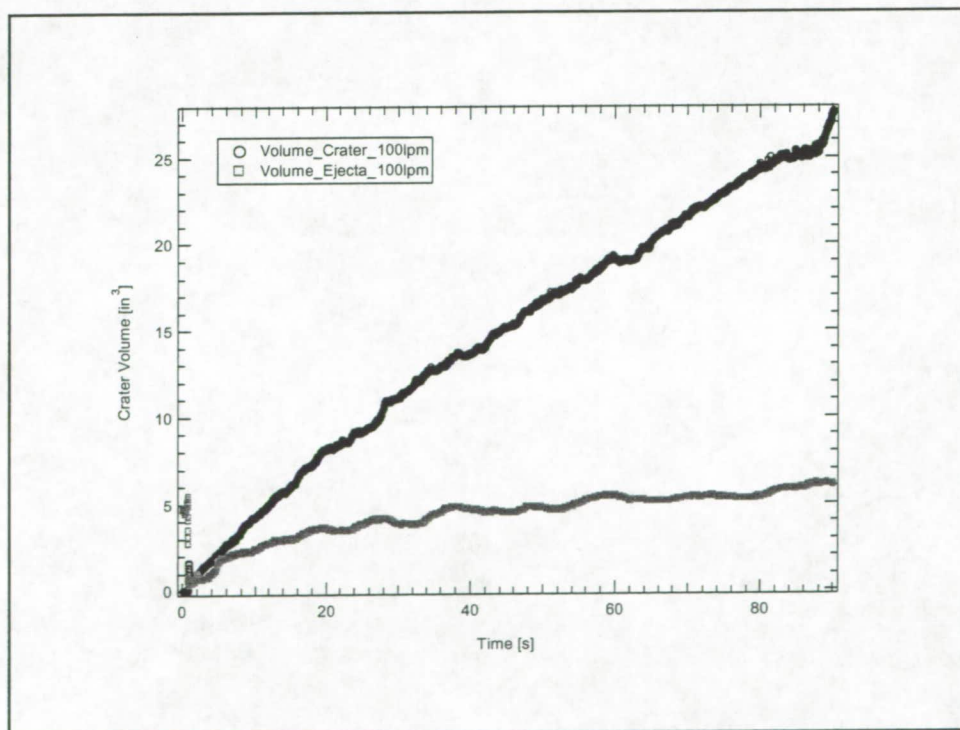
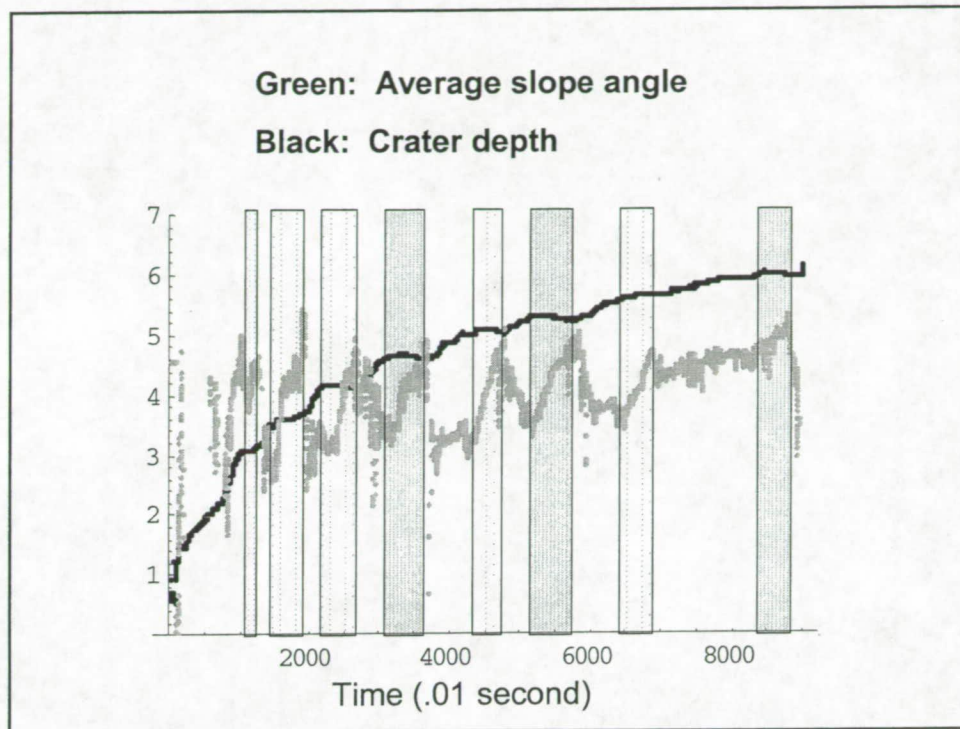


$$d/a = \ln[bt + 1], \quad t > 0$$

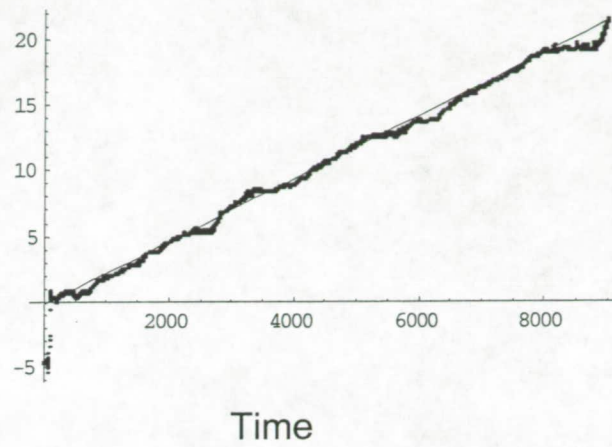
$$(\dot{d}/a) = be^{-(d/a)}, \quad t < t_0$$







### Delta Volume



### Recirculation Paths

